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Cooperative Optimization for OFDMA Resource Allocation in Multi-RRH Millimeter-Wave CRAN

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ABSTRACT Cloud radio access networks (CRAN) has become an excellent network architecture in the fifth-generation wireless communication systems, which can highly increase the capacity and coverage compared with conventional networks. However, in order to provide the best services, appropriate resource management must be applied. This article considers transmission scheduling of downlink transmission in an OFDMA-based Millimeter-Wave (mmWave) CRAN, where data transmission on each subcarrier (SC) can be used by different remote radio heads (RRHs). A joint optimization problem of user association, SC allocation, RRH allocation and power allocation is formulated to maximize the weighted sum-rate. To efficiently solve this joint optimization problem, we first divide it into two subproblems: 1) joint optimization allocation of user, RRH and SC for fixed power allocation, 2) power allocation for fixed allocation of user, RRH and SC. We propose a novel algorithm to tackle the joint optimization problem by solving these two subproblems alternately. The simulated results indicate that the proposed multi-RRH cooperative algorithm can improve the transmission performance in terms of the weighted-sum rate and power efficiency. Moreover, the proposed algorithm has low computational complexity, which ensures the feasibility of the proposed scheduling algorithm in practical systems.

INDEX TERMS Resource allocation, CRAN, millimeter-wave, OFDMA, transmission scheduling.

I. INTRODUCTION

Over the past years, increasing uses of wireless devices and high-data-rate applications have led to high demand for high-throughput wireless transmission. For instance, online games, high-definition voice and video need the support of high-speed wireless network connection. A peak transmit rate beyond 10 Giga-bit-per-second, should be achieved in the future fifth-generation (5G) wireless communication networks to support wireless data traffic [1]. To achieve this target, [2] proposed an effective method to increase the number of served base stations (BSs) deployed in a given area. In cloud radio access networks (CRAN), the conventional BSs are replaced by low-power and low complexity remote radio heads (RRHs), providing an effective method to meet the high-speed data transmission challenge [3]–[16]. The RRH is a new technology used in the base station of mobile broadband networks, which aims to improve the existing signal transmission efficiency and expand its network coverage under a simpler network architecture [17]. In this article, we pay close attention to the downlink transmission in an OFDMA based CRAN, where a large millimeter-wave multiple input multiple output antenna array is installed on each RRH. The user data will be decoded, re-encoded and finally transmitted to the users by RRHs.

Meanwhile, another challenging issue is that high-speed wireless transmission is usually associated with large power consumption. As it is shown in [18], power consumed by wireless communication devices accounts for about 3% of entire electricity consumption worldwide, which is predicted to increase sharply in 5G cellular network. More power consumption would accelerate the greenhouse effect, which is considered as a major threat to human health and social development [19]. Consequently, it is urgent to design intelligent transmission schedule policies to improve data transmission rate while reducing energy consumption.

To increase the capacity, coverage and energy efficiency, a promising technology, beamforming using massive BS antenna elements to form narrow and high-gain beams, can be employed in the 5G cellular networks. A simple analog

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beamforming technique based on a beam-switching scheme along with beam selection is proposed to enable different predetermined directions to cover the whole cell with a number of beam patterns [20]. Butler Matrix can be recognized as a typical method to create fixed beams [21]. Owing to its high capacity advantage of mmWave bands, [22] and [23] explore the application of switched-beam technology in the mmWave communication systems. For multiple beams, a key issue is how to solve joint optimization of the beams assignment and the users allocation properly, has been investigated in [24]–[28].

For conventional resource allocation problems in [29] and [30], the destination receives signal coming from multiple transmission paths such as the source and the relays, to maximize the received signal-to-noise ratio (SNR). However, CRAN can be viewed as a cooperative relay network where multiple relays (RRHs) cooperatively forward the signal from one source to one or more destinations in the downlink communication.

Most of the prior works in CRAN mainly concentrate on cellular networks with multiple BSs and users, which consider coordinated transmission and narrow-band transmission [31]. Nowadays, more and more attention has been paid to the OFDMA based multiuser transmission for the high-speed wireless cellular networks such as 5G. For example, BS coordination in an OFDMA-based multiuser transmission cellular network was studied in [32] and [33], where each BS shares user data with its neighbors on different subsets of subcarriers (SCs). However, the joint allocation of BSs, users and SCs is heuristic. Unlike all the prior works mentioned above, this article considers an OFDMA based CRAN system, where a large mmwave MIMO antenna array is installed on each RRH. Based on the OFDMA system, we assume that the data transmission on each SC can be used by different RRHs. To our knowledge, it is a novel problem and has not been considered in prior researches yet.

In our proposed OFDMA-based CRAN cellular network with orthogonal SCs and users, a linear array of equally spaced identical isotropic antenna elements is fixed on each RRH to form beams. In the covering area of CRAN, users equipped with a single antenna are uniformly distributed in the cell. Based on the OFDMA system, we assume that different RRHs can transmit user data on each SC at the same time. The purpose of this article is to deal with the joint optimization problem of user association, SC allocation, RRH allocation and power allocation. The main objective is to maximize the weighted sum-rate. The main contributions are summarized as follows.

- We consider the transmission scheduling optimization problem over OFDMA-based CRAN, where a novel assumption is proposed that the data transmission on each SC can be used by different RRHs. The joint optimization problem of user association, SC allocation, RRH allocation and power allocation is formulated to maximize the weighted sum-rate.
- In the derivation of the signal power and the interference signal power, we consider the effect of the directivity of mmWave beam on resource optimization. And the effect of the beam number on the system performance in terms of the weighted-sum rate and power efficiency is also discussed in numerical results.
- As we all know, as the number of users served by each SC increase, the weighted-sum rate of this SC will increase, but the interference among users will increase as well. In the end, the weighted-sum rate will peak off at a maximum limit. Based on this knowledge, we design a novel optimization method, to deal with the optimal allocation of each SC.
- To solve the joint optimization allocation of user, RRH, SC and power, we propose a cooperative optimization algorithm which alternately searches in the subspaces of two subproblems. The cooperative algorithm can achieve high solution quality but is not fast enough. To further improve efficiency, we propose a faster algorithm that can achieve good tradeoff between efficiency and solution quality. Simulation results demonstrate that the proposed algorithms can effectively deal with this joint optimization and improve the system performance in terms of the weighted-sum rate and power efficiency. Moreover, fast convergence ensures that the proposed scheduling algorithms are practical.

The remainder of this article is organized as follows. The system model is presented in Section II. In Section III, a joint optimization problem is formulated to improve system performance in terms of the weighted-sum rate and power efficiency. A multiple-RRH cooperative algorithm and a faster variant are proposed to tackle the joint optimization problem in Section IV. Numerical results are presented in Section V, and conclusions are drawn in Section VI.

II. SYSTEM MODEL

Consider a downlink data transmission system with a single cluster of N RRHs in an OFDMA-based CRAN with K orthogonal SCs and D users. In which, N RRHs with a linear array of M equally spaced identical isotropic antenna elements to form M fixed beams, can be denoted as $\mathcal{N} = \{1, \cdots, N\}$. In the covering area of the CRAN, the D users are uniformly distributed in the cell, and each user is equipped with a single antenna. The set of users can be defined as $\mathcal{D} = \{1, \cdots, D\}$. Based on the OFDMA system, the data transmission on each SC can be used by different RRHs, and the set of SCs can be denoted as $\mathcal{K} = \{1, \cdots, K\}$. The multiple RRHs cooperative based transmission on SC k can be shown in Fig. 1.

In the system, the data transmission on the corresponding subcarrier k between the user d and the RRH n, can be indicated by variable $c_{n,k,d}$. Assume that the subcarrier k is used by RRH n to transmit data to user d, the variable $c_{n,k,d} = 1$. Otherwise, $c_{n,k,d} = 0$.

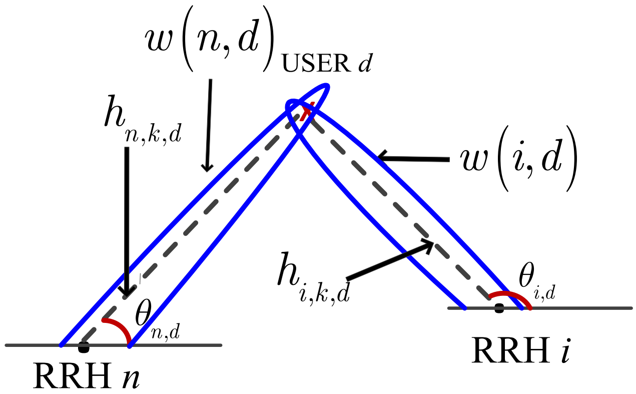


FIGURE 1. The multiple-RRH cooperative based transmission model.

Due to the constraint of the transmit power, the maximum transmit power of each RRH is assumed to be $P_{\max}$. And the transmit power of the data transmission on subcarrier k between the user d and the RRH n is indicated as $P_{n,k,d}$. The transmit power of RRH n will be satisfied as

$$\sum_{d=1}^{D}\sum_{k=1}^{K} P_{n,k,d} \leq P_{\max} \quad \forall n \in \mathcal{N}. \tag{1}$$

Each RRH is equipped with a large millimeter wave multiple input multiple output antenna array, the set of beam number can be expressed as $\mathcal{M} = \{1, \cdots, M\}$. Assume the beam m of RRH n is allocated to user d, the variable $b_{n,m,d} = 1$ can be used to denote it. Otherwise, the variable $b_{n,m,d} = 0$. Meanwhile, each beam is assumed to be allocated to one user. The allocation of beams on each RRH can be satisfied as

$$\sum_{d=1}^{D} b_{n,m,d} = 1 \quad \forall n \in \mathcal{N}, \ \forall m \in \mathcal{M}. \tag{2}$$

Butler method [21] can be applied to form the beams with $M = 2^i$ (where $i \geq 1$ is an integer). Assuming an angle of departure (AoD) of the signal between user d and RRH n is $\theta_{n,d}$, the normalized array factor of any beam $m, m = 1, 2, \ldots, M$ is given by [34]

$$A_m\left(\theta_{n,d}\right) = \frac{\sin\left(0.5M\pi\cos\theta_{n,d} - \beta_m\right)}{M\sin\left(0.5\pi\cos\theta_{n,d} - \frac{1}{M}\beta_m\right)}. \tag{3}$$

where the parameter $\beta_m = \left(-\frac{M+1}{2} + m\right)\pi$.

Due to the radiation diffusion of the transmitting power and the propagation characteristics of the channel, the signal is unavoidable to decay and produce a loss in the process of space propagation. The path loss model for system transmission can be expressed as [35]

$$PL\,[dB] = \alpha + \beta\log_{10}\left(S_{n,d}\right) + X_{\sigma_1}. \tag{4}$$

where X_{σ_1} is a zero mean Gauss random variable with a standard deviation σ_1, the variable $S_{n,d}$ is the distance between user d and RRH n, and the parameter α and β are the path loss exponent and parameter.

Assume the channel gain of the data transmission on subcarrier k between RRH n and user d is $h_{n,k,d}$, denoted as

$$h_{n,k,d} = 10^{-PL/10} \quad \forall n \in \mathcal{N}, \ \forall k \in \mathcal{K}, \ \forall d \in \mathcal{D}. \tag{5}$$

Consider the downlink data transmission, the signal power of user d on subcarrier k can be obtained as,

$$S_{k,d} = \left(\sum_{n=1}^{N}\sum_{m=1}^{M} b_{n,m,d}\left|h_{n,k,d}\right|\sqrt{D_{n,m}\left(\theta_{n,d}\right)P_{n,k,d}}\right)^2. \tag{6}$$

where $D_{n,m}(\theta)$ is the directivity of beam m in RRH n with regard to an AoD θ, given by

$$D_{n,m}(\theta) = \frac{2\left[A_{n,m}(\theta)\right]^2}{\int_0^{\pi}\left[A_n(\psi)\right]^2\sin(\psi)d\psi} \quad \forall n \in N. \tag{7}$$

Moreover, the equation (7) can be further reduced to [34]

$$D_{n,m}(\theta) = M\left[A_{n,m}(\theta)\right]^2 \quad \forall n \in \mathcal{N}. \tag{8}$$

Accordingly, the interference signal power of user d on subcarrier k can be denoted as

$$I_{k,d} = \sum_{j\neq d}\sum_{i=1}^{N}\sum_{m=1}^{M} b_{i,m,j}c_{i,k,j}\left|h_{i,k,d}\right|^2 D_{i,m}\left(\theta_{i,d}\right)P_{i,k,j}. \tag{9}$$

Given the obtained signal power and the interference signal power, the data rate of user d on subcarrier k can be described as

$$r_{k,d} = B\log_2\left(1 + \frac{S_{k,d}}{I_{k,d} + \sigma_2^2}\right). \tag{10}$$

where σ_2^2 is the variance of the additive white Gaussian noise(AWGN), which is assumed to be equal at all users. Therefore, the sum data rate of user d is given as follows

$$R_d = \sum_{k=1}^{K} r_{k,d}. \tag{11}$$

III. PROBLEM FORMULATION

In this article, we consider the transmission scheduling of downlink transmission in an OFDMA-based mmWave CRAN with the objective of obtaining the optimal transmission scheduling to solve the joint optimization allocation problem of user, SC, RRH and power to maximize the weighted sum-rate. For simplicity, three matrixes $\mathcal{B} \triangleq \left[b_{n,m,d}\right]_{\forall n\in\mathcal{N},\forall m\in\mathcal{M},\forall d\in\mathcal{D}}$, $\mathcal{C} \triangleq \left[c_{n,k,d}\right]_{\forall n\in\mathcal{N},\forall k\in\mathcal{K},\forall d\in\mathcal{D}}$ and $\mathcal{P} \triangleq \left[P_{n,k,d}\right]_{\forall n\in\mathcal{N},\forall k\in\mathcal{K},\forall d\in\mathcal{D}}$ are employed in this article. Moreover, a variable w_d is used to denote the weight of the dth user. Mathematically, the joint optimization can be formulated as the following maximization problem

$$\max_{\mathcal{B},\mathcal{C},\mathcal{P}} \sum_{d=1}^{D} w_d R_d. \tag{12}$$

subject to (1), (2) and

$$P_{n,k,d} \in [0, P_{\max}] \quad \forall n \in \mathcal{N},\ \forall k \in \mathcal{K},\ \forall d \in \mathcal{D}. \tag{13}$$
$$b_{n,m,d} \in \{0,1\} \quad \forall n \in \mathcal{N},\ \forall m \in \mathcal{M},\ \forall d \in \mathcal{D}. \tag{14}$$
$$c_{n,k,d} \in \{0,1\} \quad \forall n \in \mathcal{N},\ \forall k \in \mathcal{K},\ \forall d \in \mathcal{D}. \tag{15}$$

In problem (12), the constraints of (1) and (13) limit transmit power of each RRH. The constraints of (2) and (14) restrict that each beam of one RRH can only be allocated to one user. Whether a subcarrier is allocated to the user or not, can be shown clearly in (15). Meanwhile, for simplicity, the weight of each user w_d is assumed to be equal.

IV. JOINT OPTIMIZATION ALLOCATION OF USER, RRH, SC AND POWER

In this section, we explore how to solve the above joint optimization problem to obtain the optimal transmission scheduling, which maximize the weighted-sum rate. An alternating optimization method is proposed to solve joint optimization problem (12). Firstly, (12) is divided into two subproblems: 1) joint optimization allocation of user, RRH and SC for fixed power allocation, 2) power allocation for fixed allocation of user, RRH and SC. Secondly, we obtain an optimal solution of the joint optimization problem by solving these two subproblems alternately.

A. JOINT OPTIMIZATION ALLOCATION OF USER, RRH AND SUBCARRIER FOR FIXED POWER ALLOCATION

In this subsection, we focus on how to obtain the optimal joint allocation of user, RRH and SC for fixed power allocation. Most of the previous scheduling works, consider user association or subcarrier allocation. Only a few works consider joint optimization of user association and subcarrier allocation, such as [36], [37]. Meanwhile, these works assume that each user can only associate with one RRH in each time slot. In this article, we will propose a new joint allocation of user, RRH and SC, in which each user can be associated with multiple RRHs on each SC in each time slot.

Due to each beam of a RRH can only be allocated to one user, the beam numbers of RRH n allocated to user d (Only potentially possible) can be denoted as

$$\omega(n,d) = \arg\max_{m\in\mathcal{M}} D_{n,m}\left(\theta_{n,d}\right). \tag{16}$$

Correspondingly, the variable $b_{n,m,d}$ can be obtained as

$$b_{n,m,d} = 0 \quad \forall m \in \mathcal{M}\backslash\{\omega(n,d)\},\ \forall n \in \mathcal{N},\ \forall d \in \mathcal{D}. \tag{17}$$

Moreover, the equation (6) and (9) can be modified as

$$S_{d,k} = \left(\sum_{n=1}^{N} c_{n,k,d}\left|h_{n,k,d}\right|\sqrt{D_{n,\omega(n,d)}\left(\theta_{n,d}\right)P_{n,k,d}}\right)^2. \tag{18}$$

$$I_{d,k} = \sum_{j\neq d}\sum_{i=1}^{N} c_{i,k,j}\left|h_{i,k,d}\right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right)P_{i,k,j}. \tag{19}$$

Assume the power allocation is fixed, the joint allocation of user, RRH and subcarrier is formulated as (20), shown at the bottom of the page, which is subject to (1), (2), (13), (14) and (15).

Given that the summations and the constraints of problem (20) are independent on each SC k, the problem (20) can be decomposed into K subproblems. Without loss of generality, we focus on the kth SC for analysis, where $k \in \{1, 2, \ldots K\}$, i.e., (21), as shown at the bottom of the page, which is subject to (2), (13), (14) and

$$c_{n,k,d} \in \{0,1\} \quad \forall n \in \mathcal{N},\ \forall d \in \mathcal{D}. \tag{22}$$
$$\sum_{d=1}^{D} P_{n,k,d} \leq P_{\max} \quad \forall n \in \mathcal{N},\ \forall k \in \mathcal{K}. \tag{23}$$

Note that, there is no effective method but exhaustive search for all the possible cases can be employed to solve the joint optimization problem in (21). Obviously, this will lead to a high computational complexity especially when N, D, and K are quite large. Therefore, it is necessary to explore a new way to solve problem (21). In simplicity, a variable

$$\max_{c_{n,k,d}} \sum_{d=1}^{D}\sum_{k=1}^{K} w_d B\log_2\left(1+\frac{\left(\sum_{n=1}^{N} c_{n,k,d}\left|h_{n,k,d}\right|\sqrt{D_{n,\omega(n,d)}\left(\theta_{n,d}\right)P_{n,k,d}}\right)^2}{\sum_{j\neq d}\sum_{i=1}^{N} c_{i,k,j}\left|h_{i,k,d}\right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right)P_{i,k,j}+\sigma_2^2}\right) \tag{20}$$

$$\max_{c_{n,k,d}} \sum_{d=1}^{D} w_d B\log_2\left(1+\frac{\left(\sum_{n=1}^{N} c_{n,k,d}\left|h_{n,k,d}\right|\sqrt{D_{n,\omega(n,d)}\left(\theta_{n,d}\right)P_{n,k,d}}\right)^2}{\sum_{j\neq d}\sum_{i=1}^{N} c_{i,k,j}\left|h_{i,k,d}\right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right)P_{i,k,j}+\sigma_2^2}\right) \tag{21}$$

$$f_k(a) = \sum_{d=1}^{D} w_d B\log_2\left(1+\frac{\left(\sum_{n=1}^{N} a_{n,d}\left|h_{n,k,d}\right|\sqrt{D_{n,\omega(n,d)}\left(\theta_{n,d}\right)P_{n,k,d}}\right)^2}{\sum_{j\neq d}\sum_{i=1}^{N} a_{i,j}\left|h_{i,k,d}\right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right)P_{i,k,j}+\sigma_2^2}\right) \tag{24}$$

Algorithm 1 The Joint Allocation of User and RRH for Subcarrier k

1: Initialize set $\Pi_k = \{(n, d) \,|\forall n \in \mathcal{N}, \forall d \in \mathcal{D}\}$ and $a = 0$.

2: $\forall (n, d) \in \Pi_k$, create matrix $a'_{n,d}$ as

$$a'_{n,d} = \left[a'_{i,j}\right]_{\forall i \in \mathcal{N}, \forall j \in \mathcal{D}} = \begin{cases} 1 & i = n, j = d \\ a_{i,j} & otherwise \end{cases} \tag{25}$$

3: Obtain pair of RRH and user from

$$\left(n^*, d^*\right) = \arg \max_{\forall (n,d) \in \Pi_k} \left\{ f_k \left(a'_{n,d}\right)\right\}. \tag{26}$$

4: if $f_k\left(a'_{n^*,d^*}\right) > f_k(a)$, let $a = a'_{n^*,d^*}$ and $\Pi_k = \Pi_k \setminus \{(n^*, d^*)\}$, then continue from Step 2.

5: Obtain the joint allocation of user and RRH $c_{n,k,d}$ for SC k as follow,

$$c_{n,k,d} = a_{n,d} \quad \forall n \in \mathcal{N}, \ \forall d \in \mathcal{D}. \tag{27}$$

$a = \left[a_{n,d}\right]_{\forall n \in \mathcal{N}, \forall d \in \mathcal{D}} \in \{0, 1\}^{|\mathcal{N}| \times |\mathcal{D}|}$ and a function $f_k(a)$ of subcarrier k given in (24), as shown at the bottom of the previous page, are employed.

As the number of users served by SC k increases, the weighted-sum rate of subcarrier k will increase, and the interference between users will increase as well. As a result, the weighted-sum rate will increase to its peak and remain unchanged. Algorithm 1 is proposed to obtain the optimal allocation policy of SC k. Firstly, the combinatorial set of all RRHs and users is initialized as Π_k and an empty set a is initialized to denote the available pairs of RRH and user. Secondly, using (25) and (26) to choose the optimal pair of RRH and user (n^*, d^*) in Π_k to get the maximum weighted-sum rate when adding to set a. Thirdly, adding (n^*, d^*) to a as a'_{n^*,d^*}, then computing and comparing the weighted-sum rate of a'_{n^*,d^*} and a respectively. When $f_k\left(a'_{n^*,d^*}\right) > f_k(a)$, the available set a will be updated as $a = a'_{n^*,d^*}$ and then delete the pair (n^*, d^*) from Π_k. Subsequently, the set a will be the final optimal allocation policy of subcarrier k if it has no update. The details of this algorithm can be shown in Algorithm 1.

Algorithm 2 DCA Method for Solving (28)

1: Initialize $\mathcal{P}[0]$ and let $s = 1$.

2: Obtain $\mathcal{P}[s]$ by solving (31) through interior point method.

3: Let $s = s + 1$ and go to Step 2 until $\mathcal{P}[s]$ converges.

B. POWER ALLOCATION UNDER FIXED JOINT ALLOCATION OF USER, RRH AND SUBCARRIER

In this subsection, we discuss power allocation under fixed allocation of user, RRH and subcarrier. For given $c_{n,k,d}$ $\forall n \in \mathcal{N}, \forall k \in \mathcal{K}, \forall d \in \mathcal{D}$, the optimal problem (12) can be represented as (28), shown at the bottom of the page, subject to (1), (2), (13), (14) and (15).

This subsection aims to get the optimal $P_{n,k,d}$ to maximize the weighted sum-rate under the constraints of power in (13). Specially, when $N = 1$ and $D = 1$, the conventional water-filling algorithm will be useful to solve problem (28). However, for the transmission cellular network with multiple RRHs and SCs, the optimization problem will be much more complicated because of the interference of inter-RRH and inter-subcarrier. In this situation, the interference will be impacted by scheduling policy and signal to interference plus noise ratio (SINR). Therefore, the conventional water-filling algorithm will not be applicable any more. Because (9) is differentiable, the objective function can be recognized as the difference of two concave functions (DC) programming problem (29) and (30), as shown at the bottom of the page, [38].

To solve this problem, we can employ the DCA method [39] to achieve a close-to-optimal solution. For the problem in (28), it is approximated as the following problem at the sth iteration,

$$\max_{\mathcal{P}} g(\mathcal{P}) - h(\mathcal{P}[s-1]) - \nabla h^T (\mathcal{P}[s-1]) (\mathcal{P} - \mathcal{P}[s-1]). \tag{31}$$

subject to (1), (2), (13), (14) and (15).

In general cases, the convergence of DCA method has been proved to a KKT optimal point in [36]. The details of how to exploit DCA method to tackle the problem (28) is demonstrated in Algorithm 2.

$$\max_{P_{n,k,d}} \sum_{d=1}^{D} \sum_{k=1}^{K} w_d B \log_2 \left(1 + \frac{\left(\sum_{n=1}^{N} c_{n,k,d} \left| h_{n,k,d} \right| \sqrt{D_{n,\omega(n,d)}\left(\theta_{n,d}\right) P_{n,k,d}} \right)^2}{\sum_{j \neq d} \sum_{i=1}^{N} c_{i,k,j} \left| h_{i,k,d} \right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right) P_{i,k,j} + \sigma_2^2} \right) \tag{28}$$

$$g(\mathcal{P}) = \sum_{d=1}^{D} \sum_{k=1}^{K} w_d B \log_2 \left(\sum_{j \neq d} \sum_{i=1}^{N} c_{i,k,j} \left| h_{i,k,d} \right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right) P_{i,k,j} + \left(\sum_{n=1}^{N} c_{n,k,d} \left| h_{n,k,d} \right| \sqrt{D_{n,\omega(n,d)}\left(\theta_{n,d}\right) P_{n,k,d}} \right)^2 + \sigma_2^2 \right) \tag{29}$$

$$h(\mathcal{P}) = \sum_{d=1}^{D} \sum_{k=1}^{K} w_d B \log_2 \left(\sum_{j \neq d} \sum_{i=1}^{N} c_{i,k,j} \left| h_{i,k,d} \right|^2 D_{i,\omega(i,j)}\left(\theta_{i,d}\right) P_{i,k,j} + \sigma_2^2 \right) \tag{30}$$

C. JOINT OPTIMIZATION ALLOCATION OF USER, RRH, SUBCARRIER AND POWER

In above subsections, we have obtained the optimal joint optimization allocation of user, RRH and subcarrier for fixed power allocation in Algorithm 1, and a KKT optimal power allocation for fixed joint allocation of user, RRH and subcarrier. In this subsection, we explore an alternating optimization method to solve the joint optimization of user allocation, RRH allocation and subcarrier allocation, and power allocation. The overall algorithm is summarized as Algorithm 3.

Algorithm 3 Multiple-RRH Cooperative Algorithm for Solving (12)

1: Initialize $\mathcal{P}[0]$ and $i = 1$.
2: Based on $\mathcal{P}[i-1]$, update $\tilde{c}_{n,k,d}(i)$ through Algorithm 1.
3: Forming the *ith* approximately convex problem by employing $\mathcal{P}[i-1]$, and Solve this convex problem using Algorithm 2, then update $\mathcal{P}[i]$.
4: Let $s = s + 1$ and go to Step 2 until the weight-sum rate converges.

For the multiple-RRH cooperative algorithm proposed in Algorithm 3, We can get the computational complexity on the basis of its process. In step 2, the method proposed in Algorithm 1 is used to determine the subcarrier allocation, with the computational complexity of $O(K \times N \times D)$. Assuming the iteration number of algorithm 2 is L_P, the computational complexity of the DCA algorithm in step 3 can be computed as $O\left(L_P KND^2\right)$. Then assuming the iteration number of the proposed multiple-RRH cooperative algorithm is L_J, the computational complexity of the algorithm 3 can be obtain as $O\left(L_J KND + L_J L_p KND^2\right)$.

D. THE LOW COMPLEXITY ALGORITHM

In this subsection, we propose a low complexity algorithm to solve the optimization problem in (12). In this low complexity algorithm, we first assume the transmission power is equally allocated to each subcarrier; then, according to algorithm 1, the joint allocation of RRH, subcarrier and user $c_{n,k,d}$ $(\forall n \in \mathcal{N}, \forall k \in \mathcal{K}, \forall d \in \mathcal{D})$ is obtained when the power is fixed; finally, the DCA method of algorithm 2 is used to get the optimal power allocation. The detailed description of low complexity algorithm is shown in Algorithm 4. According to the analysis of the computational complexity of the multiple-RRH cooperative algorithm in the previous section, the computational complexity of this low complexity algorithm is $O\left(KND + L_P KND^2\right)$.

V. NUMERICAL RESULTS

In this section, we provide numerical results to show the feasibility of the proposed methods in an OFDMA based CRAN. In order to prove the superiority of the proposed algorithms, an extremely effective joint optimization allocation algorithm of user, SC, and power in OFDMA heterogeneous networks [36], is employed as a reference. The difference between the reference algorithm and the proposed algorithms is that, in this article we assume each user can be connected to different RRHs on each SC. And the proposed algorithms also consider the optimal selection of RRHs, which can decline the interference of different RRHs and lower the power consumption.

Algorithm 4 The Low Complexity Algorithm for Solving (12)

1: Initialize $\mathcal{P} = P_{\max}/K$ $(\forall k \in \mathcal{K})$ and $c_{n,k,d} = 0$ $(\forall n \in \mathcal{N}, \forall k \in \mathcal{K}, \forall d \in \mathcal{D})$.
2: Given $\mathcal{P}$, update $c_{n,k,d}(i)$ according to Algorithm 1.
3: Using $\tilde{c}_{n,k,d}(i)$, obtain $\mathcal{P}[i]$ through algorithm 2.

This section compares the performance of the proposed algorithms and the reference algorithm in terms of weighted-sum rate and the power efficiency through simulation. We consider a cellular network shown in Fig. 2, in which the N RRHs are uniformly distributed in a $1000m \times 1000m$ grid area with lm spacing of the adjacent RRHs, and the K users are uniformly distributed in the grid area. For each RRH, there are three sectors to form a smart antenna beam, as shown in Fig. 3. Based on the 3GPP LTE-A standard [33], the OFDMA wireless access channel is assumed to be divided into $N = 128$SCs, which is centered at a frequency of 73GHz and has a bandwidth B = 20MHz. The explicit parameters of path loss and large-scale fading in (4) have been given in Table 1 according to [40]. The noise power spectral density is −174dBm/Hz with a noise figure of $\sigma_2 = 7$dB at all the receivers. The parameter setting is listed in Table 1 [34], [35].

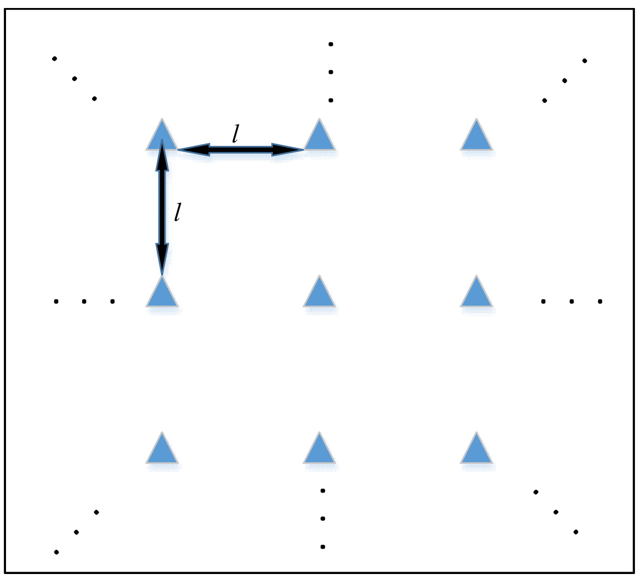


FIGURE 2. The simulation scenario of OFDMA-based CRAN.

Fig. 4 shows the transmission performance versus the number of users. This investigation is ordered under the condition that the adjacent RRH spacing l is fixed as 200m, the

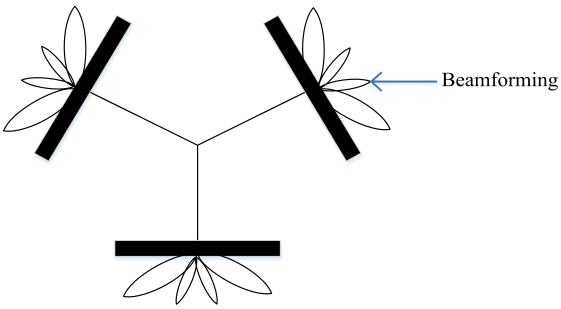


FIGURE 3. The smart antenna of RRH.

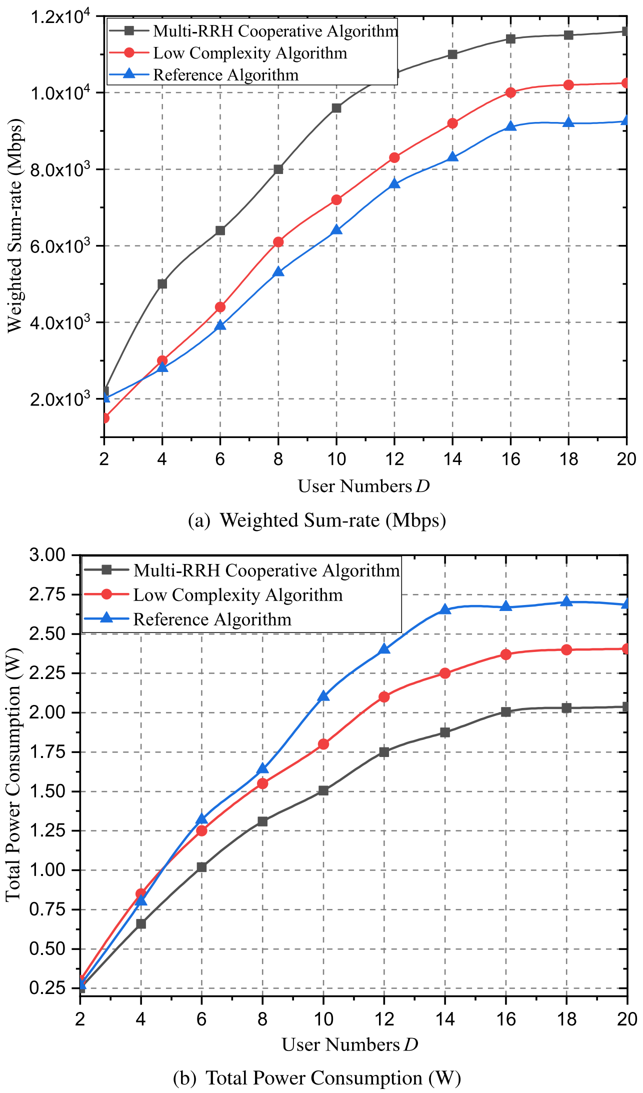


FIGURE 4. Transmission performance versus user numbers D with $l = 200m$, $P_{max}= 24$ dBm, and $M = 16$.

maximum transmit power of each RRH $P_{\max}$ is set as 24dBm, and the number of beams M is considered as 16. It can be seen that with the increase of users D, more users will carry out data transmission. As a result, the weighted-sum rate and total power consumption will increase. However, when the number of users is too large, some users will be unable to use the RRHs for data transmission effectively, which will result in no increase of the weighted-sum rate and power consumption.

TABLE 1. Simulation parameters.

Parameters	Definition	Value
B	Bandwidth	20MHz
w_d	Weight of each user	1
K	Number of SCs	128
α	Path loss exponent	38
β	Path loss parameter	30
σ_1	magnetization	6dB

Fig. 5 studies the transmission performance versus the adjacent RRH spacing l. In this experiment, the number of users D is 14, the maximum transmit power of each RRH $P_{\max}$ is 24dBm, and the number of beams M is 16. When the adjacent RRH spacing lm is too small, the density of the RRH is large, which means, more RRHs can be employed

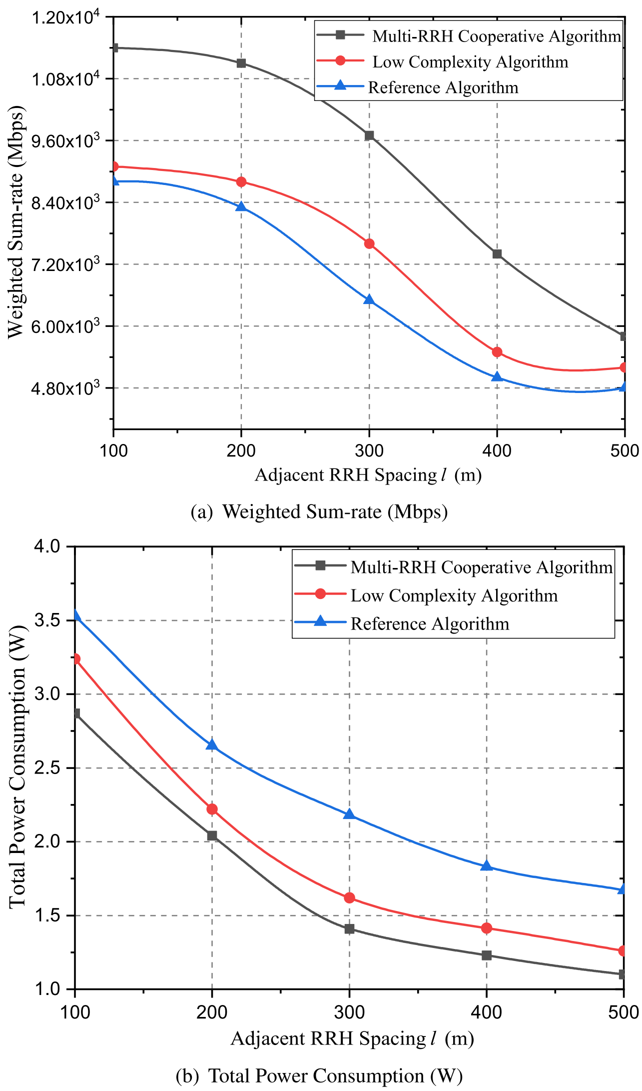
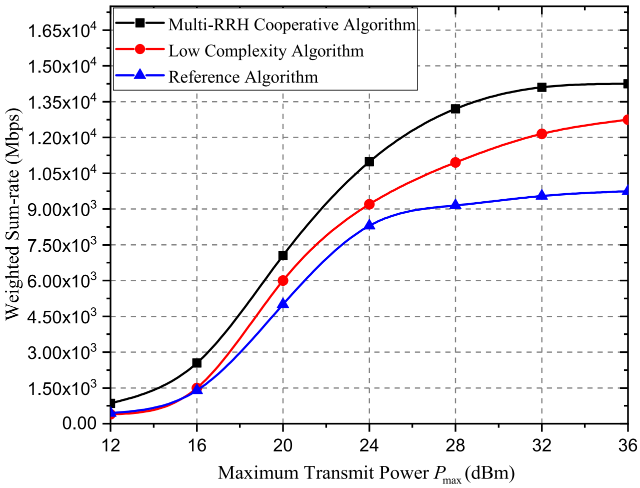
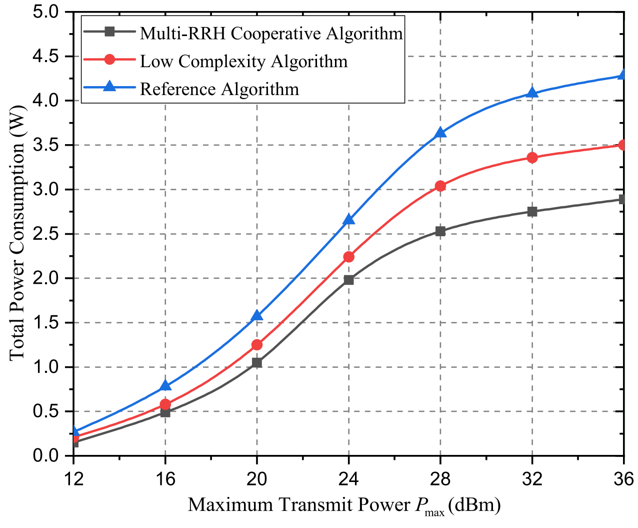


FIGURE 5. Transmission performance versus adjacent RRH spacing l with $D = 14$, $P_{max}= 24$ dBm, and $M = 16$.

by users. That will improve the total weighted-sum rate and the total power consumption will increase as well. However, the decrease of adjacent RRH spacing will lead to a sharp increase of the total power consumption, but will not bring a large improvement of the total weighted-sum rate. The reason is that, although large density of the RRHs can serve more users, the interference among users will increase rapidly at the same time. Therefore, the total weighted-sum rate improves little.



(a) Weighted Sum-rate (Mbps)

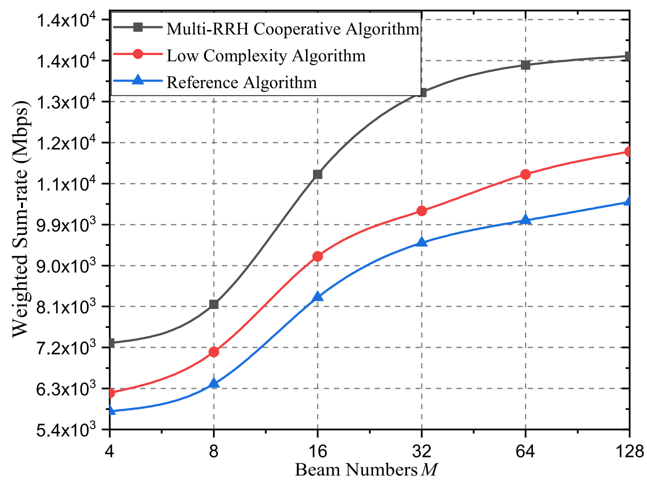


(b) Total Power Consumption (W)

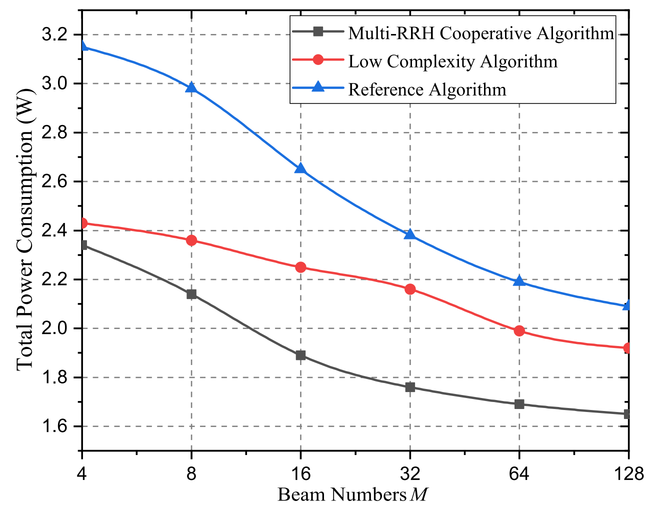
FIGURE 6. Transmission performance versus maximum transmit power of each RRH P_{max} with $D = 14$, $l = 200m$, and $M = 16$.

Fig. 6 explores the influence of the maximum transmitting power of each RRH P_{max} on the performance of the system when the adjacent RRH spacing l is 200m, the number of users D is 14 and the number of beams M is 16. With the increase of the maximum transmit power of each RRH, the coverage of RRHs will be expanded to serve more users. This will lead to the improvement of the total weighted-sum rate and the total power consumption will increase as well. Moreover, due to more users can be severed by RRHs, the interference among users will also increase. Thus, the increasing rate of the total weighted-sum rate will slow down and the total weighted-sum rate will increase to its peak gradually and keep unchanged.

Fig. 7 discusses the influence of the number of beams M on the performance of the system when the adjacent RRH spacing l is 200m, the number of users D is 14, and the maximum transmit power of each RRH P_{max} is 24 dBm. Normally, the increase of the number of beams will bring a narrow beam width, which leads to a better directionality and stronger anti-interference ability. Based on that feature, a higher transmission rate can be obtained by using lower power consumption.



(a) Weighted Sum-rate (Mbps)



(b) Total Power Consumption (W)

FIGURE 7. Transmission performance versus beam number M with $P_{max} = 24dBm$, $D = 14$, and $l = 200m$.

As it is shown above, the proposed multi-RRH cooperative algorithm and the low complexity algorithm can allocate resources more efficiently and achieve better performance than the reference algorithm. The main reason is that the proposed multi-RRHs cooperative algorithm and the low complexity algorithm can utilize more RRHs to transmit user

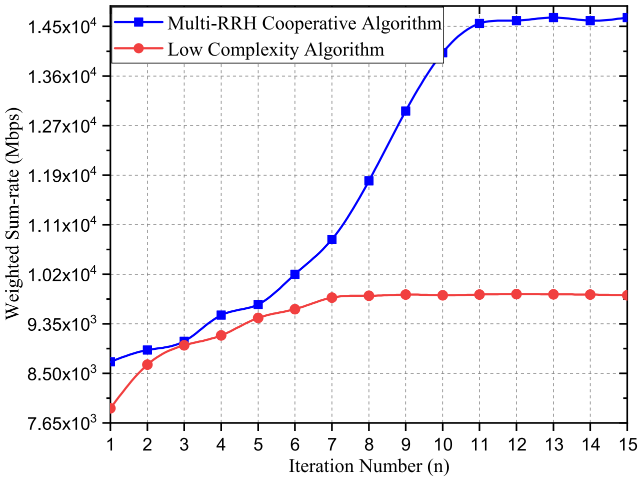


FIGURE 8. Transmission performance versus iteration number with $P_{\max} = 24dBm$, $D = 14$, $l = 200m$, and $M = 16$.

data on each SC, while in the reference algorithm, only one RRH can be used on each SC. Meanwhile, the proposed multi-RRHs cooperative algorithm can get the optimal policy for this joint optimization problem through numerous iterations. However, the low complexity algorithm does not tend to obtain the global optimal solution even the local optimal solution because it has only one iteration. Therefore, the transmission performance of the multi-RRH cooperative algorithm is better than that of the low complexity algorithm.

Fig. 8 demonstrates the impact of the number of iterations on the changes of the total transmission rate when the number of users D is 14, the adjacent RRH spacing l is 200m, the number of beams M is 16 and the maximum transmission power of each RRH $P_{\max}$ is $24dBm$. At the beginning of the iteration, the system does not get the optimal resource allocation strategy, so the system gets a low transmission rate. As the number of iterations increases, the resource allocation becomes more and more close to the optimal strategy, and the transmission rate improves significantly and reaches the optimal. As shown in Fig. 8, the optimal iteration number of algorithm 2 and algorithm 3 is approximately 8 and 12 respectively. Moreover, the calculation complexity $O\left(L_J KND + L_J L_p KND^2\right)$ of multi-RRH cooperative algorithm and $O\left(KND + L_P KND^2\right)$ of the low complexity algorithm are relatively low. From the view of practical systems, both the two proposed algorithms can be used to deal with this optimization issue effectively and improve the system performance quickly.Therefore, the proposed multi-RRH cooperative algorithm can solve this optimization problem effectively, which has important research significance and practicability.

VI. CONCLUSION

This article focuses on the transmission shceduling of downlink transmission in an OFDMA-based mmWave CRAN, where the data transmission on each SC can be used by different RRHs. A joint optimization problem of user allocation, SC allocation, RRH allocation and power allocation is formulated to maximize the weighted sum-rate. To solve this problem, we divide the joint optimization problem into two subproblems. The first one is joint optimization allocation of user, RRH and SC for fixed power allocation, and the second one is optimal power allocation for fixed allocation of user, RRH and SC. Sequentially, we propose a novel multiple-RRH cooperative based method to obtain the optimal scheduling by solving these two subproblems alternately. Meanwhile, we proposed a low complexity algorithm to solve this joint optimization issue. Simulation result shows that our proposed optimization algorithms can achieve better performance than the conventional algorithms. Moreover, we also explore the convergence of the proposed algorithms. The result demonstrates the optimal iteration number of the proposed algorithms are quite small, which highlights the feasibility of the proposed algorithms.

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